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Enhancing Vitamin Composition in Quail Eggs with FITODOC® Carnitine Supplementation

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Micronutrient deficiencies are a global health concern, driving interest in functional animal products as accessible dietary sources of essential vitamins. Poultry eggs, particularly those from Japanese quail (*Coturnix coturnix japonica*), are widely consumed and valued for their nutrient density, making them suitable vehicles for biofortification. Given this context, exploring innovative feed additives such as FITODOC® Carnitine offers a practical approach to improving the vitamin content of quail eggs and, consequently, their nutritional value for human diets. This study investigated the potential of FITODOC® Carnitine, a multicomponent feed additive containing L-carnitine, betaine hydrochloride, DL-methionine, and inositol, to enhance the vitamin composition of quail eggs. Sixty quails were allocated into three groups: a control group on a basal diet, an experimental group supplemented with FITODOC® at 3 mL/L of drinking water for 14 days, and a second experimental group supplemented for 28 days. Vitamins A, B_2, E, D_3, and β-carotene were quantified using high-performance liquid chromatography and spectrophotometry, with statistical analysis performed using Student's t-test ($p < 0.05$). Results revealed a duration-dependent enrichment of all measured vitamins, with increases ranging from 25-63% for vitamins A, B_2, and E, 13-25% for vitamin D_3, and 139-222% for β-carotene compared with controls. FITODOC® Carnitine effectively improves the multivitamin profile of quail eggs, which highlighted its potential for producing functional foods that address nutritional gaps in human diets.

Keywords: FITODOC® Carnitine; functional foods; poultry nutrition; L-carnitine; bioactive compounds, quail eggs.

INTRODUCTION

The worldwide demand for functional foods is increasing as consumers seek nutrient-dense products that contribute to health and disease prevention (Rakonjac et al., 2024; Agus et al., 2022). Consumed on a large scale, eggs with their balanced nutritional profile and the potential to further increase in bioactive compounds via dietary manipulation represent one of the most convenient and cost effective vehicles for functional food enrichment (Bourre, 2005; Kralik et al., 2023). Thus, poultry nutrition research has transitioned from single focus on production towards production of so-called functional eggs fortified with vitamins, minerals, carotenoids and polyunsaturated fatty acids having health benefits beyond basic nutrition (Alagawany et al., 2018; Kavtarashvili et al., 2017). This paradigm shift is driven by the necessity to combat global micronutrient malnutrition and satisfy consumer demand for sustainable and functional foods.

Quail eggs are an ideal vehicle for functional foods due to their high nutritive value and favorable production characteristics (Arthur & Bekaiei, 2017). Quail eggs possess high protein, vitamin, and mineral content, and their cholesterol concentration is lower than that of other eggs. This is associated with lower levels of triglycerides, making them a valuable dietary choice for health-conscious consumers (Jeke et al., 2018). The Japanese quail (*Coturnix coturnix japonica*) is a fast-growing, early sexually mature and disease-resistant species, which also provides an excellent source for enrichment of value-added functional eggs (Razmaite et al., 2022; Usturoi et al., 2025). Inclusion of bioactive compounds in quail eggs appears promising for the diversification of functional foods and improving the sustainability of the poultry industry (Sarmiento-García et al., 2023).

Research has consistently demonstrated that dietary manipulation is able to affect the biochemical composition of eggs and both macronutrients and micronutrients in feed may

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have roles in nutrient deposition (Kavtarashvili et al., 2017; Schiavone & Barroeta, 2011). The fat-soluble vitamins A, D_3, E, and β-carotene, along with the water-soluble B-group vitamins, are of particular importance because they play essential roles in antioxidant defense, bone health, immune function, and neurological activity in humans (Shiryaeva & Karnaukhova 2016; Bourre & Galea 2006). The biofortification of eggs with these vitamins enhances their use as functional foods and supports public health by combating widespread deficiencies in a variety of populations (Bourre, 2005; Radanović et al., 2023). However, most interventions to date have examined the effect of single vitamins or fatty acids in isolation, limiting the understanding of synergistic enrichment strategies (Zielińska-Dawidziak et al., 2024; Digambar et al., 2018).

Some enrichment strategies with natural plant-derived additives, microalgae, or antioxidant supplements have succeeded in altering the nutrient profile of eggs (Boiago et al., 2019; Mattioli et al., 2022). For example, in quail eggs, omega-3 fatty acid and carotenoid contents are increased through the use of Spirulina, Dunaliella and other microalgae product while antioxidant status and immune system response are enhanced (El-Hack et al., 2024; Lei et al., 2017). Yolks are rich in β-carotene with the addition of purple carrot powder, blessing them β-benefits and aditional eggshell quality and antioxidant activity (Sarmiento-García et al., 2023). In addition, egg carotenoids contents, antioxidant activity and functional traits are enhanced by plant-based nutraceuticals such as moringa, goji berries and some botanical extracts (Maisto et al., 2022). Although these studies demonstrated the possibility of natural additives to improve specific bioactive substances, they typically focus only on fatty acids or carotenoids and do not cover all enrichment types of multivitamins (Vlaicu et al., 2023; Dumitru et al., 2023).

Due to its crucial role in lipid metabolism and fatty acid transport, as well as its potential to enhance the bioavailability of fat-soluble vitamins in poultry products, the amino acid L-carnitine represents a promising feed additive (Manukyan & Aidinyan, 2015; Prakash et al., 2024). Additional bioactive components such as betaine, DL-methionine, and inositol have recognized effects on metabolic efficiency, antioxidant capacity, and nutrient deposition. However, little is known about their combined action with L-carnitine, particularly regarding vitamin enrichment in eggs (Kurnia et al., 2012).

Studies indicate that administration of multiple components may yield synergetic effects through optimizing absorption and deposition of several vitamins at once (Kralik et al., 2023; Kavtarashvili et al., 2017). This potential, however, is still rarely explored as integrated approaches are limited for quail nutrition and represent a main knowledge void in the field of functional egg (Guyonnet, 2015; Digambar et al., 2018).

Methodological complications with functional egg production are also an obstacle, since many studies provide conflicting results on nutrient bioavailability, bioefficacy, and consumer acceptance (Guyonnet, 2015; Zielińska-Dawidziak et al., 2024). Supra-nutritional levels of vitamins C and E may enhance antioxidant capacity but can negatively affect egg production traits if not carefully balanced (Sigolo et al., 2019; Chitra et al., 2013). Similarly, excessive supplementation of folic acid or microminerals may reduce amino acid content or compromise egg quality, emphasizing the need for precise dose optimization (Yu et al., 2024). Research on biofortification consistently demonstrates that an integrated dietary approach yields greater nutrient stability, bioavailability, and synergistic effects compared to isolated supplementation (Alagawany et al., 2018; Kralik et al., 2023). Recent enrichment studies in quail nutrition increasingly explore innovative feed ingredients developed with advanced technologies such as nanotechnology, lipid blends, and natural emulsifiers, which enhance antioxidant protection, nutrient stability, and digestibility of bioactive compounds (Serpa et al., 2023; Al-Khalaifah et al., 2024). Multi-component supplements combining microelement glycinates with β-carotene have been shown to improve the bioavailability of iron, zinc, manganese, and retinol (Schiavone & Barroeta, 2011), while formulations integrating vitamins, carotenoids, and polyunsaturated fatty acids provide superior stability and health benefits compared to single-nutrient fortification (Digambar et al., 2018; Panse et al., 2016).

However, there remains a clear gap in understanding how such multi-component formulations affect the concentrations of vitamins A, B_2, E, D_3, and β-carotene in quail eggs (Zielińska-Dawidziak et al., 2024). FITODOC® Carnitine, a proprietary premix containing L-carnitine, betaine, DL-methionine, and inositol (Prakash et al., 2004), was developed to enhance nutrient utilization and metabolic activity in poultry. Given its combined methyl-donor capacity, antioxidant protection, and lipid-metabolism efficiency, this additive may synergistically improve vitamin deposition in eggs (Kurnia et al., 2012; Kralik et al., 2023).

To address this significant knowledge gap, the present study was designed to determine the impact of FITODOC® Carnitine supplementation on the concentrations of vitamins A, B_2, E, and D_3, as well as β-carotene, in quail eggs (Digambar et al., 2018; Zielińska-Dawidziak et al., 2024). The present study will therefore determine the impact of FITODOC® Carnitine supplementation on the quantities of vitamins A, B_2, E and D_3 together with β-carotene in quail eggs. Considered from the perspective of functional food design, nutritional biofortification and feed additive utility, this study fills a significant gap in research and presents new evidence on multicomponent strategies for functional egg production. The results of the present study will contribute to a better understanding about the ability of FITODOC® for enhancing egg quality.

MATERIALS AND METHODS

***Experimental Site*:** The study was conducted at the Department of Parasitology and Veterinary and Sanitary Expertise, Moscow State Academy of Veterinary Medicine and Biotechnology (K.I. Skryabin MGAVMiB - MVA, Moscow, Russia). All experimental procedures were approved by the institutional ethics committee and adhered to international guidelines for the care and use of experimental birds, consistent with recent poultry enrichment studies (Rakonjac et al., 2024; Usturoi et al., 2025).

***Feed Additive*:** The test additive was FITODOC® Carnitine (OOO "Agrovetservice," Russia), a water-soluble, colorless to yellow liquid containing L-carnitine, betaine hydrochloride, DL-methionine, and inositol. The additive was freshly diluted in drinking water at the manufacturer's recommended concentration before administration. Multicomponent feed additives containing carnitine and related bioactive compounds have been widely applied to enhance nutrient utilization and improve egg composition (Bachinskaya et al., 2025; Bocharova et al., 2024).

***Experimental Design and Bird Management*:** A total of 60 Japanese quails (*Coturnix coturnix japonica*), 30 days old, were allocated into three groups (n = 20 per group) following the principle of analog pairs to ensure homogeneity in body weight and productivity. Quails are well-recognized as a reliable model for functional egg enrichment due to their high productivity and adaptability (Bachinskaya et al., 2025; Murtazaev et al., 2022). Birds were housed in a three-tier cage system under controlled environmental conditions: 22-24 °C temperature, 55-60% relative humidity, and a 16 h light: 8 h dark photoperiod. Feed and water were provided *ad libitum*. All birds received a basal compound feed (Megakorm DK-52, Russia) formulated for productive quails according to GOST 18221-98. The dietary treatments are summarized in Table 1.

Table 1. Experimental design.

Group	Birds (n)	Diet description	Supplementation period
Control	20	Basal diet + water only	—
Exp.1	20	Basal diet + FITODOC® Carnitine (3 ml/L in water)	Day 30-43 (14 days)
Exp.2	20	Basal diet + FITODOC® Carnitine (3 ml/L in water)	Day 30-57 (28 days)

***Egg Sampling*:** Eggs were collected daily, and representative samples (n = 5 per group per week) were selected for vitamin analysis. Only intact, freshly laid eggs were used. Yolks were separated, homogenized, and stored at −20 °C until analysis. Sampling strategies in this study align with previous nutritional enrichment research in quails and chickens (Rakonjac et al., 2024; Dumitru et al., 2023).

***Vitamin Determination*:** Vitamin A (retinol) was quantified by high-performance liquid chromatography (HPLC) using a Dionex UltiMate™ 3000 system (Thermo Fisher Scientific, USA; Chromeleon software v. 3.0.1) according to GOST R 54635-2011. Vitamin B_2 (riboflavin) was determined fluorometrically on a LUMACHROM system (Lumex Instruments, Russia; software v. 1.2.5) per GOST EN 14152-2020. Vitamins E (α-tocopherol) and D_3 (cholecalciferol) were analyzed using HPLC with ultraviolet detection following GOST EN 12822-2003 and GOST EN 12821-2003, respectively. β-carotene was quantified spectrophotometrically at 450 nm on a UNICO 2100 (United Products Instruments, USA; software v. 2.1) with results verified by HPLC. Analytical approaches were consistent with recent poultry studies assessing egg vitamin and carotenoid profiles (Razmaite et al., 2022; Dumitru et al., 2023). All reagents were of analytical grade (Sigma-Aldrich, USA), and each analysis was conducted in triplicate.

***Statistical Analysis*:** Data were expressed as mean ± standard error of the mean (M ± m). Statistical analyses were performed using SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA). Differences between groups were assessed by Student's *t*-test, with statistical significance set at $p < 0.05$. The analytical and statistical approach followed standard procedures for evaluating feed supplementation in poultry nutrition trials (Egila et al., 2023; Serpa et al., 2023).

RESULTS AND DISCUSSION

FITODOC® Carnitine supplementation markedly enhanced the vitamin composition of quail eggs, with consistent increases observed across vitamins A, B_2, E, D_3, and β-carotene relative to the control group (Table 2). These results indicate that targeted feed additives can significantly enrich eggs with bioactive compounds, supporting the growing interest in functional animal-derived foods (Rakonjac et al., 2024; Vlaicu et al., 2023).

The concentration of vitamin A increased from 0.16 ± 0.03 mg/100 g in the control to 0.20 ± 0.04 mg/100 g after 14 days (+25%) and 0.23 ± 0.05 mg/100 g after 28 days (+43.8%). These results suggest that FITODOC® Carnitine enhances retinol deposition through improved lipid transport and antioxidant protection. Similar increases were reported in studies using polyphenol-rich additives that stabilized retinol and improved its bioavailability in egg yolk (El-Hack et al., 2022; Rakonjac et al., 2024). The results are also consistent with recent findings that feed modification strategies can modulate the profile of fat-soluble vitamins in designer eggs (Zielińska-Dawidziak et al., 2024).

Riboflavin showed a marked increase from 0.40 ± 0.02 mg/100 g in the control to 0.55 ± 0.03 mg/100 g (+37.5%) after 14 days and 0.65 ± 0.04 mg/100 g (+62.5%) after 28 days. This enhancement may result from improved metabolic utilization of precursors such as methionine and betaine, which support enzymatic activity. Recent reports confirm that dietary interventions can stimulate B-vitamin accumulation in

Table 2. Effect of FITODOC® Carnitine on the vitamin composition of quail eggs (Mean ± SE, per 100 g edible portion).

Vitamin / Compound	Control	Experimental 1 (14 days)	% Change vs. Control	Experimental 2 (28 days)	% Change vs. Control
Vitamin A (mg)	0.16 ± 0.03	0.20 ± 0.04	+25.0%	0.23 ± 0.05	+43.8%
Vitamin B_2 (mg)	0.40 ± 0.02	0.55 ± 0.03	+37.5%	0.65 ± 0.04	+62.5%
Vitamin E (mg)	0.80 ± 0.05	1.00 ± 0.06	+25.0%	1.30 ± 0.08	+62.5%
Vitamin D_3 (mg)	1.60 ± 0.07	1.80 ± 0.08	+12.5%	2.00 ± 0.09	+25.0%
β-carotene (mg)	0.18 ± 0.01	0.43 ± 0.03	+139%	0.58 ± 0.04	+222%

Note: Values represent mean ± standard error (SE), n = 20 per group. Percent change calculated relative to control group. Differences between groups were significant at $p < 0.05$ (Student's t-test).

eggs by modulating gut microbiota and nutrient absorption (Egila et al., 2023; Jiang et al., 2023). These outcomes highlight the additive's potential to address dietary gaps in riboflavin intake, particularly in populations reliant on eggs as an affordable nutrient source (Usturoi et al., 2025).

Tocopherol levels rose significantly from 0.80 ± 0.05 mg/100 g in the control to 1.00 ± 0.07 mg/100 g (+25%) after 14 days and 1.30 ± 0.09 mg/100 g (+62.5%) after 28 days. Vitamin E enrichment improves oxidative stability of egg yolk lipids, thereby extending egg shelf life. Similar benefits have been documented with natural antioxidant supplementation in poultry diets (Dumitru et al., 2023; Al-Khalaifah et al., 2024). Furthermore, Dumitru et al. (2023) emphasized that plant-derived antioxidants can enhance tocopherol stability, which aligns with the present findings.

The vitamin D_3 content increased from 1.60 ± 0.12 mg/100 g in the control to 1.80 ± 0.15 mg/100 g (+12.5%) and 2.00 ± 0.18 mg/100 g (+25%) in the experimental groups. Though the percentage change was smaller than for other vitamins, the nutritional importance is substantial, given widespread vitamin D deficiencies globally. Rakonjac et al. (2024) highlighted that feed-based interventions can enrich fat-soluble vitamins, including D_3, while Kralik et al. (2023) confirmed the potential of multi-enriched eggs to supply key micronutrients.

The largest relative increase was observed for β-carotene, which rose from 0.18 ± 0.014 mg/100 g in the control to 0.43 ± 0.032 mg/100 g after 14 days (+139%) and 0.58 ± 0.041 mg/100 g after 28 days (+222%). This sharp rise suggests that FITODOC® Carnitine promotes carotenoid absorption and protects against oxidative degradation. Comparable findings were reported in quail eggs supplemented with plant-based pigments, which significantly increased yolk carotenoid concentrations (Razmaite et al., 2022; Sarmiento-García et al., 2023). Furthermore, Yu et al. (2024) demonstrated that feed fortification strategies directly influence carotenoid and folate deposition in eggs, reinforcing the current study's results.

The observed vitamin enrichment can be linked to the additive's synergistic components. L-carnitine enhances fatty acid transport and mitochondrial oxidation, facilitating fat-soluble vitamin deposition. Methionine and betaine support hepatic metabolism and methylation, improving nutrient utilization, while inositol enhances antioxidant defense and stabilizes sensitive compounds such as carotenoids and tocopherols. These mechanisms align with reports that dietary strategies based on bioactive compounds can enrich eggs in a sustainable and consumer-relevant way (Vlaicu et al., 2024; Prakash et al., 2024).

Our findings confirm that FITODOC® Carnitine can be used as a nutritional tool to enhance quail eggs, contributing to the concept of "designer eggs" that address human micronutrient deficiencies. Similar conclusions were reached by Dumitru et al. (2023) and Vlaicu et al. (2023), who emphasized the dual role of functional feeds in improving animal performance and creating enriched foods. With the rapid rise in consumer demand for functional products, these results highlight a scalable strategy for producing eggs with improved vitamin profiles and health-promoting properties (Usturoi et al., 2025).

***Conclusion*:** The present study demonstrated that FITODOC® Carnitine supplementation significantly enhanced the vitamin profile of quail eggs, particularly increasing the levels of vitamins A, B_2, E, D_3, and β-carotene. The effect was dose-dependent with prolonged administration, showing the highest enrichment after 28 days. These improvements are likely due to the synergistic action of the additive's components, which optimize nutrient metabolism, antioxidant protection, and deposition in egg yolk.

The findings highlight the potential of FITODOC® Carnitine as a practical nutritional strategy for producing designer quail eggs enriched with bioactive compounds that support human health. Given the growing consumer demand for functional foods, these results offer both scientific and industry relevance. Future studies should investigate the long-term safety, economic feasibility, and consumer acceptance of such enriched eggs to support their broader adoption in sustainable poultry production.

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***Availability of data*:** Data supporting the findings of this study are available from the corresponding author upon reasonable request.

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***Policy referred*:** FAO/WHO Nutrition Improvement Guidelines; Functional Food and Biofortification Policies; Sustainable Livestock Nutrition Frameworks.

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